

ACCURACY ANALYSIS OF TDRSS DEMAND FORECASTS

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Abstract

This paper reviews Space Network (SN) demand forecasting experience over the past 16 years and describes methods used in the forecasts. The paper focuses on the Single Access (SA) service, the most sought-after resource in the Space Network. Of the ten years of actual demand data available, only the last five years (1989 to 1993) were considered predictive due to the extensive impact of the Challenger accident of 1986.

NASA's Space Network provides tracking and communications services to user spacecraft such as the Shuttle and the Hubble Space Telescope. Forecasting the customer requirements is essential to planning network resources and to establishing service commitments to future customers. The lead time to procure Tracking and Data Relay Satellites (TDRSs) requires demand forecasts ten years in the future - a planning horizon beyond the funding commitments for missions to be supported.

The long range forecasts are shown to have had a bias toward underestimation in the 1991 - 1992 period. The trend of underestimation can be expected to be replaced by overestimation for a number of years starting with 1998. At that time demand from new missions slated for launch will be larger than the demand from ongoing missions, making the potential for delay the dominant factor. If the new missions appear as scheduled, the forecasts are likely to be moderately underestimated.

The SN commitment to meet the negotiated customer's requirements calls for conservatism in the forecasting. Modification of the forecasting procedure to account for a delay bias is, therefore, not advised. Fine tuning the mission model to more accurately reflect the current actual demand is recommended as it may marginally improve the first year forecasting.

BACKGROUND

NASA's Space Network (SN) provides tracking and communications services to user spacecraft such as the Shuttle and the Hubble Space Telescope. The Space Network space segment consists of operational geostationary Tracking and Data Relay Satellites (TDRSs) at longitudes of 41W, 174W, partially operational satellites at 171W and 275W, and a spare at 46W. TDRSs are controlled from the White Sands Ground Terminal (*Cacique*) and the Second TDRSS Ground Terminal (*Danzante*) in New Mexico. Each TDRS communicates with user spacecraft by using one of two Single Access (SA) antennas or by using a multiple-access phased array antenna.

The SN began to support customers in late 1983 with the launch of TDRS-1. Implementation of the complete system of three relay spacecraft was delayed by loss of Challenger along with its TDRS-2 payload in January 1986. The accident also brought about a re-evaluation and a slowdown in the pace and number of Shuttle-launched missions, many of which were slated for SN support.

Shuttle operations resumed in September 1988 with the successful launch of TDRS-3. Six months later, TDRS-4 was launched. The completion of checkout of the third operational TDRS in June 1989 marked the initiation of a fully operational SN. Mission load grew from early support of Shuttle, Landsat 4 and 5, ERBS, SME, and SMM to include COBE, HST, UARS, EUVE, TOPEX, and classified missions. Replenishment of aging relay spacecraft and the addition of spare capacity was accomplished with launches of TDRS-5 and -6 in 1992 and 1993.

MISSION MODEL HISTORY AND PURPOSE

The generation of a "mission model" for the prediction of the users and their communications requirements has been a key activity since early in the formation of the tracking networks. Major studies for the Spaceflight Tracking and Data Network (STDN) – as the ground-based network was known – were conducted yearly, with additional updates in between as demanded. When plans for the creation of the TDRSS (or the Space Network, as it later became to be known) began to emerge, the studies began to include prospective TDRSS users. Starting in 1978, the first study devoted to TDRSS was produced.

The primary purpose of the Network Support Capability Studies (also referred to as loading studies or forecasts) was to ensure that the projected TDRSS would have adequate resources to handle the upcoming customers so that a commitment to potential new customers could be made. This purpose is still valid, but in more recent years the activity has grown in importance as support for the procurement of replenishment TDRS and, consequently, has been the subject of close scrutiny within and outside the agency.

Unfortunately, mission modeling is not an exact science. Political and economic environment, unforeseen technical problems, and technology developments tend to determine actual events and diminish the validity of the forecast. On the other hand, some stability is lent to the model by the tendency for operational missions to be extended beyond their original planned life as expected new missions fail to happen.

MISSION MODEL AND DEMAND MODEL DEVELOPMENT

The first step in developing the mission model is to survey the mission planning offices at the NASA centers and NASA Headquarters for Space Network user requirements documents, written or in process. Any missions not yet approved require confirmation of the appropriate program office at NASA Headquarters. Additional offices at the centers or Headquarters are surveyed for information on non-NASA programs, such as those of other government agencies or commercial or foreign entities, that are planning on Space Network support.

After all the missions using the Space Network have been identified, an examination of the overall telecommunications requirements is performed, and the missions are prioritized to facilitate schedule conflict arbitration. Although requirements documentation states the needs of the respective missions, a meeting or conversation with mission project representatives generally provides additional useful information, such as operational constraints, relationships with other missions, further explanations of the mission goals, and relative importance of the specific support requirements. This information, along with the experience of the analyst, is sometimes used to extend the mission duration from that formally stated in the documented requirements. The list of prioritized missions and requirements thus developed constitutes the *mission model*.

The mission model is then further developed into a *demand model*. This is the aggregate of all the mission requirements on the Space Network. Set up activity, such as Single Access (SA) antenna repositioning (slew) time, is also included. This aggregate is then compared to the availability of the Space Network resources by using the Network Planning and Analysis System (NPAS). The results are provided as the percentage of the customer's requirements that can be met.

For the purposes of this analysis a simplified version of the demand model is used and referred to as *demand forecast* (or simply *forecast*). In the demand forecast, detailed mission requirements,

such as orbit and number of contacts per day, are reduced to the average total SA hours per day required in each year or quarter-year of the forecast period. The total SA hours include the effect of two minutes of slew time per communications contact.

The *actual demand* data are taken from monthly network support reports. A valid comparison with the demand projections requires that the Shuttle be in flight. Because the monthly report data include intermittent Shuttle flights, the actual Shuttle data were subtracted from the monthly totals and the effect of a Shuttle in flight was adjusted by adding the assumed full-period shuttle support. This permits the use of all the monthly data points. Actual demand data also include the effect of slew time.

MISSION MODEL CHRONOLOGY

The earliest mission model data for the Space Network (SN) are found in a Network Support Capability Study of July 1976. Five missions were listed to have TDRSS support as soon as it became operational in early 1981. Because no specific TDRSS service requirements were provided, a demand forecast is not available for analysis.

Beginning in December 1978, more detailed studies were conducted at least yearly. Eight studies spanning the period from 1978 to 1993 were analyzed for this paper. A summary of the model characteristics is provided in Table 1, followed by further description of their contents.

Table 1. Characteristics of Mission Models Used in Study

Model Name	Pub Date	Years	No.*	STS-V, STS-K**	Other Significant SA Missions (4 to 24 hr/day)	No. Approved or in orbit
1978	12/78	81-90	22	Yes	HST, LANDSAT, ADV. GEOL, STEREO SAT, OER	27%
1980	10/80	84-88	21	Yes	HST, LANDSAT-D, NOS	29%
1982	6/82	84-89	13	Yes	HST, LANDSAT-D	59%
1985	2/85	85-91	11	Yes	HST	64%
1989	5/88	89-97	19	No	SSF, HRSO, HST, EOS, TRMM	47%
1990	10/89	90-97	18	No	SSF, HST, EOS, TRMM, HRSO	79%
1992	3/92	92-99	17	No	SSF, HST, TRMM, EOS, LSAT-7, AXAF	100% (11 in orbit)
1993-1	—	93-99	15	No	SSF, HST, TRMM, EOS, LSAT-7	100% (9 in orbit)

* Only missions with a single-access requirement are included.

** A Vandenberg Air Force Base-launched Shuttle (STS-V) supported simultaneously with a Kennedy Space Center-launched Shuttle (STS-K). An STS-K is included in all studies.

The 1978 and 1980 models are characterized by optimistic projection for a large number of users for the yet-to-be built network. Most missions were in their study phase, and were included in the models because the budget environment appeared to support them. Large requirements for STS-K (Kennedy) and STS-V (Vandenberg) dominate these early models, as well as those produced through 1985. Requirements for simultaneous support of the second Shuttle begin between calendar years 1984 and 1985. The models assume that both Shuttles are required simultaneously but with varying contact time needs. The total contribution of the Shuttles therefore varies from one to two full links.

The 1989 and the later models are characterized by faded optimism and greater scrutiny of Shuttle-launched missions, resulting from the 1986 Challenger accident. A steadily diminishing set of study missions is included. The final two models include no study missions – all the missions are either in orbit or approved.

The 1989 model was produced in May 1988, several months before the resumption of Shuttle flights. The 1989 and later models include only a Kennedy-launched Shuttle; Vandenberg had, by then, been dropped as a Shuttle launch site.

The 1989 and 1990 models also included HRSO. The requirement was for a full link in the first model and was reduced to 10 hours per day in the 1990 model. The mission was dropped out in the later models. HRSO is the most significant consideration in comparing the 1989 model with those of 1990 and 1992.

All models, starting with that of 1989, also include a continuous coverage requirement for Space Station, resulting in a step increase in demand. Slips in Space Station start dates moved the requirement start from late 1995 into 1996. The program further slipped to 1998 start date causing a noticeable change to the 1993-1 model.

FORECASTS VERSUS ACTUAL DEMAND

All eight forecasts as well as the actual demand are plotted for comparison in Figure 1. The plot suggests a division of the studies into two sets: 1978 to 1985 and 1989 to 1993. The first set covers the pre-Challenger accident as well as the pre-operational SN period. The second set covers the period where the SN is near or at full operation.

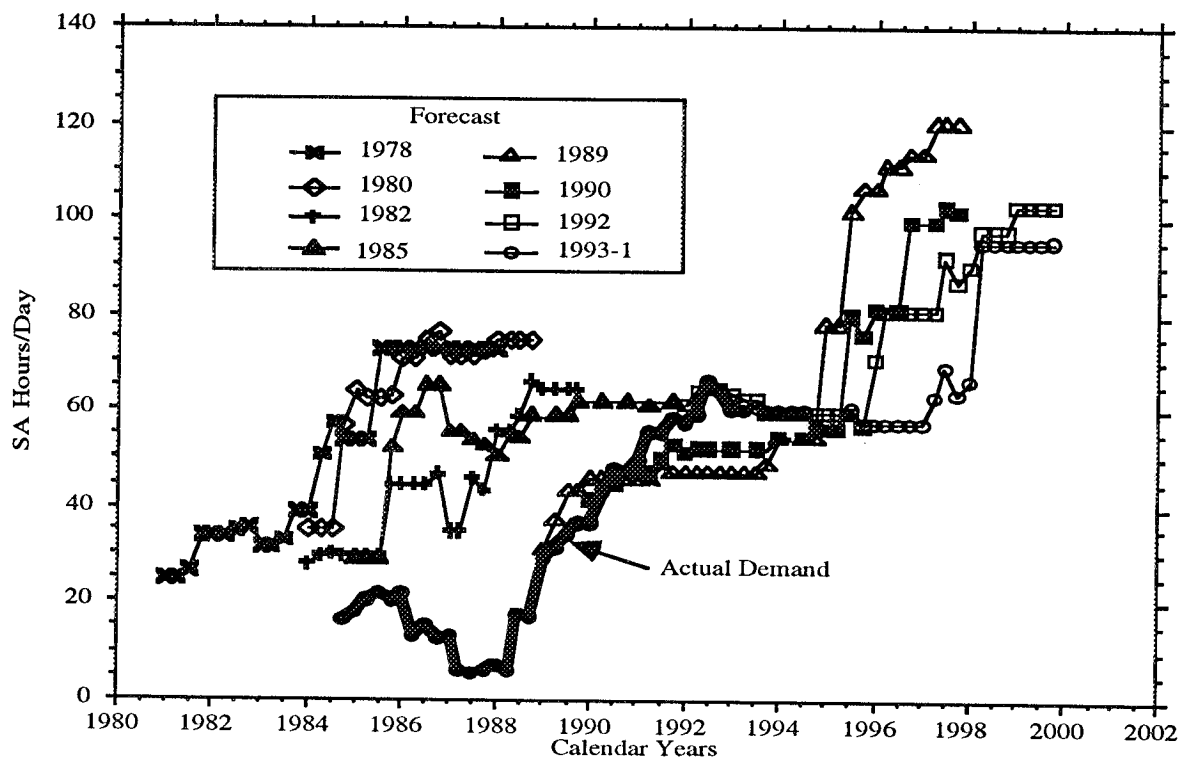


Figure 1. Comparisons of Forecasts and Actual Demand.

As stated previously, the Challenger accident suspended all shuttle launches for 32 months. An attempt was made to account for the Shuttle suspension period by sliding the early forecasts out 32 months. The resulting altered plot improved the predictions but substantial differences

remained between forecasts and actual. It appears that the change in launch rate and suspension of some missions curtailed the originally predicted user build-up.

The maturity of the Space Network may have been another factor in the accuracy of the forecasts. The percentage of approved and ongoing missions for each Model (see Table 1) appears to be correlated with the accuracy of the forecasts. Unfortunately, the Challenger accident masks an accurate analysis of this effect for the forecasts made 1978 through 1985.

It is useful to examine the uncertainty in the forecasts beginning with 1989 under an assumption that the forecasts are updated to reflect more accurate information. If the mission model from the forecast of 1989 is compared to the forecast of 1993, a net loss of one mission is expected due to the change in forecast span, yet a loss of 4 missions occurred. Six missions were lost (four never occurred and two were removed due to forecast span) whereas two were gained (one due to the forecast span and the other an unexpected user). In Table 1 the 1993 forecast is shown to be fully approved with a majority ongoing, while only 47% of the missions in the 1989 model were approved. This suggests that at least two or three of the four missions lost can be attributed to the lack of approval.

STATISTICAL ANALYSIS OF 1989-1993 DEMAND PROJECTIONS

Due to the extensive impact of the Challenger accident of 1986, only the post-Challenger forecasts are considered predictive. The statistical analysis is therefore limited to the forecasts beginning with 1989. Visual analysis of the 1989-1993 forecasts plotted in Figure 1 suggest that in the short term the forecasts are relatively accurate, experiencing small errors due to fluctuations in actual demand. Large changes in forecast are due to user program changes in the out-years.

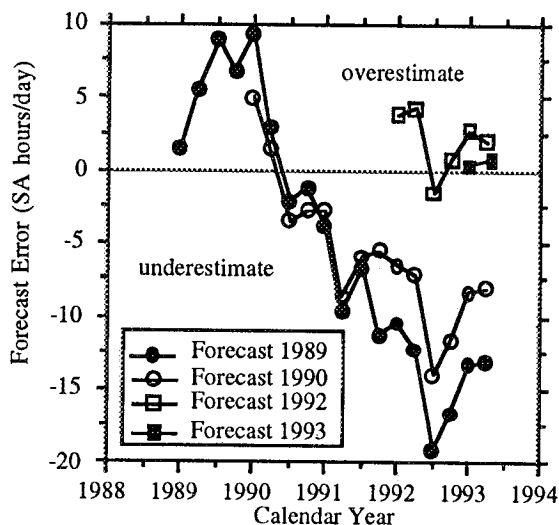


Figure 2. Error in Forecasts Versus Date.

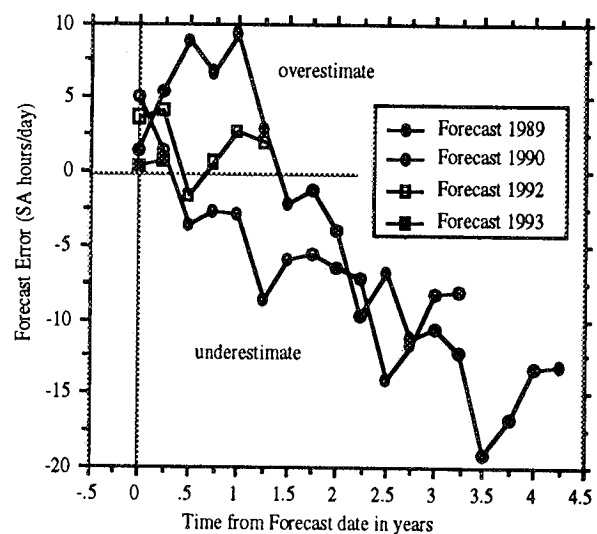


Figure 3. Error in Forecasts Versus Time from Forecast

Short-Range Forecast Errors. Figures 2 and 3 show the difference between forecasted SA hours and the actual demand. Positive differences indicate overestimation. In Figure 2 the errors are plotted as a function of the year for which the forecast was made, whereas in Figure 3 the errors are plotted as a function of time from when the forecast was made. The figures show that there has been a tendency to overestimate in the first year or so into a forecast and increasingly

The SN commitment to meet the negotiated customer's requirements calls for conservatism in the forecasting. This requires that only statistically convincing (likely to be true) evidence be used to modify the mission model. Modification of the forecasting procedure to account for a delay bias is not advised. Fine tuning the mission model to more accurately reflect the current actual demand is recommended as it may marginally improve the first year forecasting...

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